Unattended Radiation Sensor Systems for Remote Terrestrial Applications and Nuclear Nonproliferation

Lodewijk van den Berg, Alan E. Proctor, Ken R. Pohl, Alex Bolozdynya and Raymond DeVito

Constellation Technology Corporation,
Largo, Florida 33777

Abstract. The design of instrumentation for remote sensing presents special requirements in the areas of power consumption, long-term stability, and compactness. At the same time, the high sensitivity and resolution of the devices needs to be preserved. This paper will describe several instruments suitable for remote sensing developed under the sponsorship of the Defense Threat Reduction Agency (DTRA). The first is a system consisting of a mechanical cryocooler coupled with a high-purity germanium (HPGe) detector. The system is portable and can be operated for extended periods of time at remote locations without servicing. The second is a hand-held radiation intensity meter with high sensitivity that can operate for several months on two small batteries. Intensity signals above a set limit can be transmitted to a central monitoring station by cable or radio transmission. The third is a small module incorporating one or more high resolution mercuric iodide detectors and front end electronics. This unit can be operated using standard electronic systems, or it can be connected to a separately designed, pocket-size module that can provide power to any detector system and can process detector signals. It incorporates a shaping amplifier, a multichannel analyzer, and gated integrator electronics to process the slow signal pulses generated by room temperature solid state detectors. The fourth is a high pressure xenon (HPXe) ionization chamber filled with very pure xenon gas at high pressure, so that the efficiency and spectral resolution are increased above the normally available gas-filled tubes. The performance of these systems will be described and discussed.

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INTRODUCTION

The necessity to perform observations and measurements of nuclear radiation at remote locations has led to the development of sensors and supporting instrumentation that can operate for months or years without maintenance or servicing. In addition, these systems often need to be compact and lightweight, have minimal power consumption, and withstand adverse environmental conditions.

This paper will describe several systems developed by Constellation Technology Corporation (Constellation) that conform to the requirements stipulated above. These systems can also be used advantageously for more normal, routine measurement

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applications, where they provide significant savings in manpower, measurement time, and logistical supplies.

ELECTROMECHANICALLY COOLED DETECTOR

The electromechanically cooled high-resolution detector (EMC) has been designed to replace a liquid nitrogen cooled equivalent detector. The EMC, shown in Figure 1, is man-portable and suitable for use in locations where liquid nitrogen is not available, or frequent attention is inconvenient and time-consuming. The “box” section contains a Stirling engine cryocooler and associated electronics. The detector section contains a conventional high-purity germanium (HPGe) detector, preamplifier, and temperature sensor to control the cooling system. Several types of detectors can be used interchangeably, which allows the EMC to serve multiple applications.

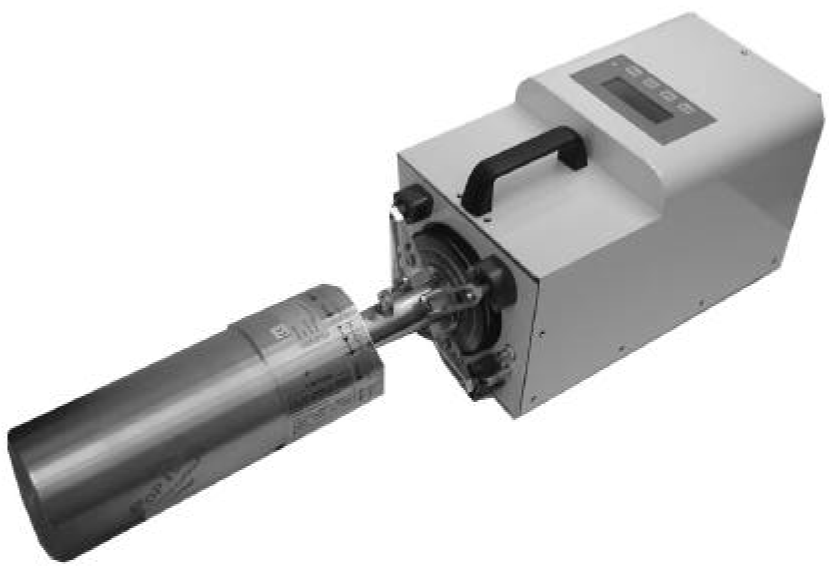

FIGURE 1. Photograph of electromechanically cooled detector system

The EMC is usually powered from a 12 VDC supply in the transport case, but any equivalent 12 VDC source, such as a vehicle battery, is acceptable. The power supply in the transport case can operate from a 100-240 VAC/50-60 Hz source and includes a 12 V rechargeable battery which can operate the cryocooler for 40 minutes during transport or external power interruption.

The performance of the EMC detector is comparable to that of liquid nitrogen cooled detectors, with minor degradation in resolution at low energies due to mechanical vibration and electrical noise. A typical example of a high-resolution energy spectrum is shown in Figure 2.

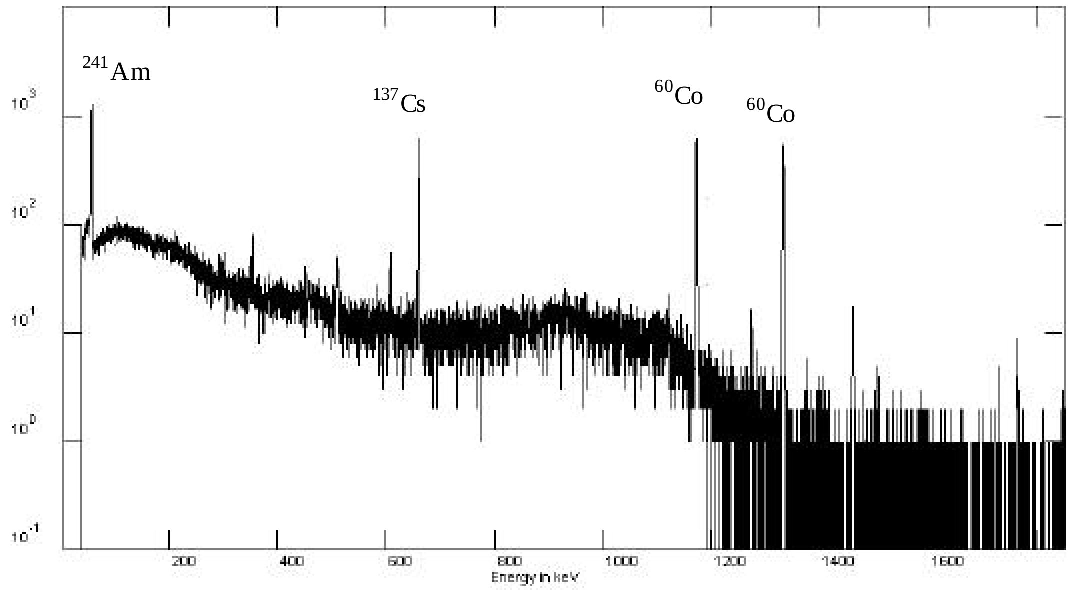

FIGURE 2. High energy spectrum acquired with mechanically cooled HPGe detector

The EMC was developed for arms control inspectors to use at sites where liquid nitrogen is not available. Inspectors would ship the EMC to their base location, cool the detector overnight, transport it to the measurement site while operating on battery power, and perform the inspection. While the EMC is more costly than liquid nitrogen cooled detectors or other commercially available mechanically cooling systems, no other detector combines the portability, operational capability, and freedom from cryogens.

RADIATION INTENSITY COUNTER

The radiation intensity counter is a small, self-contained pocket-size instrument that is suitable for safeguard, environmental, and non-proliferation applications. The sensing element consists of a 25 mm x 25 mm x 5 mm mercuric iodide detector that operates as a counter, although regions of interest can be defined. The unit provides a sensitivity of <20 microrad/hour at 662 keV, and can operate for several months on two small alkaline batteries. Figure 3 shows a photograph of this device.

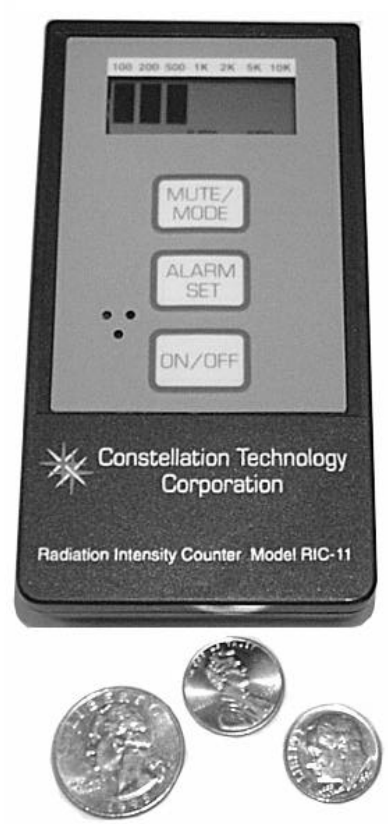

FIGURE 3. Photograph of radiation intensity counter (RIC)

The count rate is visually presented to the user in the form of a liquid crystal bar graph. Electronic or audible alarms will be generated when the radiation intensity exceeds a preset level. The instrument can be carried for personal protection, or can be permanently installed for monitoring or surveying applications. In that case, the electronic alarm signal can be transmitted to a central monitoring station.

MERCURY MODULE

The Mercury Module is a small metal enclosure with dimensions 90 mm x 50 mm x 50 mm. It contains a mercuric iodide detector with dimensions of up to 25 mm x 25 mm x 3 mm, a preamplifier, and other elements of the front-end electronics. Mercuric iodide detectors are very efficient because of the high density and the high atomic number of the material, and they can operate at ambient temperatures without cooling. Since the detectors are configured as modular units, they can be stacked on top of each other to increase the active detector volume to approximately 7.5 cm^3. Figure 4 shows a photograph of the Mercury Module.

FIGURE 4. Photograph of Mercury Module

The base of the module contains the connections for the high voltage, the power supply for the preamplifier, and the detector signal output. The module can be operated using a standard NIM power supply and signal processing unit. An example of the energy spectrum measured using a mercury module is shown in Figure 5.

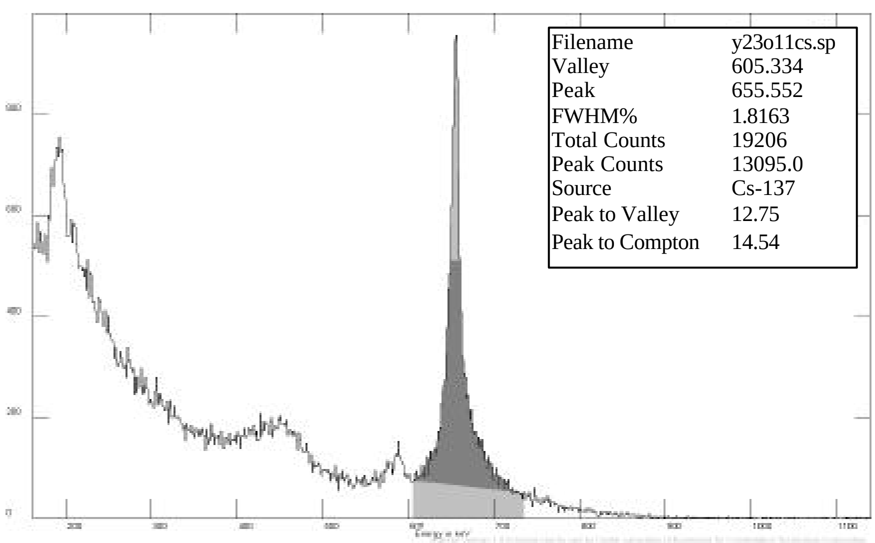

FIGURE 5. Spectrum of ^{137}Cs radiation measured with a mercuric iodide detector

The compact size of the Mercury Module makes it well suited for measurements in confined spaces or for incorporation in hand-held systems. The modules can also be permanently installed in areas of high radiation density because of the high resistivity to radiation damage of the mercuric iodide detectors.

MICROMAX

The use of compact, light-weight portable sensor systems for remote applications requires that the power supply and signal processing system to support the sensors can equally be operated with a minimum of resources. These features are incorporated in a small, pocket-size unit called the MicroMax, which contains a surface-mount high voltage supply, a shaping amplifier with gated integrator, and a multichannel analyzer. Figure 6 shows a photograph of the MicroMax.

FIGURE 6. Photograph of MicroMax

The bias supply in this package can be adjusted up to 4000 V, so that the system can be used with a variety of detector systems. The shaping time is usually set at 2 microseconds, and the integrator times can be adjusted between 6 and 20 microseconds. The gated integrator system is especially useful when using detectors with slow risetime pulses, where the integrated charge is a better evaluation of the energy of a gamma ray photon than the height of the signal pulse. The number of channels in the analyzer can be set from 512 to 4096, so that spectra with different resolution can be adequately analyzed. The data from the analyzer can be displayed on and stored in a pocket-size PC attached to the MicroMax. The package consisting of sensor, MicroMax, and PC can be operated for approximately 48 hours on 2 AA batteries included in the MicroMax. This system is especially useful in combination with a Mercury Module since the mercuric iodide detector has a very low leakage current.

HP XENON DETECTORS

A portable xenon spectrometry system has been developed which combines the high spectral resolution of xenon detectors with PC based operating controls. The use of extremely high purity gas at high pressure results in improved resolution and increased efficiency. The detector contains 0.8 kg of gas and its dimensions are 12 cm diameter and 30 cm long. The sensitive area is therefore large in all directions. The system operates over a temperature range of 5-60^{o}C and the detector is radiation hard. A photograph of the basic detector and PC arrangement is shown in Figure 7.

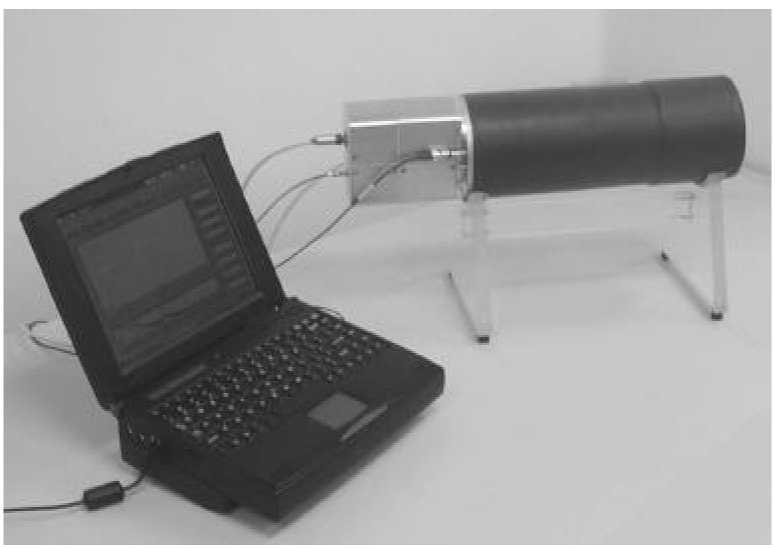

FIGURE 7. Photograph of xenon detector arrangement

The PC provides power to the high voltage system and the preamplifier and processes the signals from the detector using a PC/MCA board. This MCA provides up to 4096 channels at variable shaping times so that it can be used with different types of detectors.

This system can be used in airborne instrumentation or for the monitoring of nuclear facilities.

SUMMARY

Several systems developed for the unattended and remote sensing of nuclear radiation have been described. Critical parameters in the design of these systems were reliability, long-term stability, compactness, comfortable portability for one person, and low power consumption whenever possible. We have approached several of these requirements with the use of unusual detector configurations and newly developed efficient detector materials. This was combined with the application of advanced electronic systems to the detector power supply and signal processing. Several of these systems have general applications, for example in environmental x-ray fluorescence analysis, in neutron activation analysis, and for the measurement of ionizing radiation in space experiments.

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